RHI MAGNESITA

The Role of Modelling and Simulation in Refractory Product Development for the Steel Industry

K1-Met Simulation Conference 2025

Vienna, 23.04.2025

Agenda

- Company info
- Simulation overview
- Steelmaking Examples
- Continuous Casting Examples
- Summary

The global leader in refractories

There for you, wherever you need us

65 production sites
(incl. raw material sites)

12 recycling facilities

+100 countries shipped to worldwide

5 R&D hubs and centres

20,000
Employees

€ 3.5bn
2024 revenue

+ 1,700
Active patents

€ 83m
Investment in R&D and Technical Marketing

A complex range of tailored refractory products and solutions

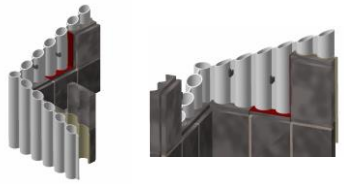
Bricks

1 Permanent lining

2 Non-basic, ex. Alumina

3 Basic, ex. Mag-Carbon

Tile system - Didotherm Fix



Monolothics & pre cast

4 Mixes

5 Pre Castables

Digital Solutions

APO

Functional products

6 Slide Gates

7 Nozzles

8 Purge Plugs

9 ISO

Systems & Machinery

Simulation

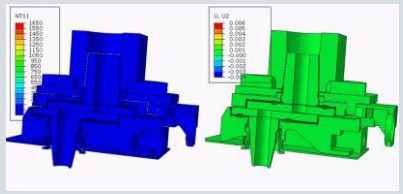
What and how

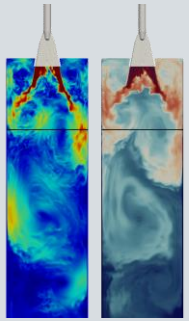
Application of state of the art simulation technology to:

- Predict the behaviour of refractory materials/shapes in use and deepen process understanding
- Understand and describe possible failure mechanisms and derive solutions
- Support Development and Engineering of lining concepts and advanced refractory products

Numerical methods

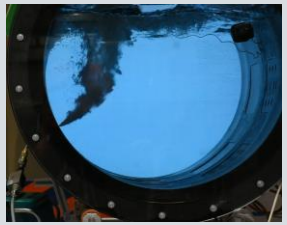
- Deformation/stress analyses
- Material behaviour
- Temperature distributions
- Fluid Flow analyses
- Thermodynamics

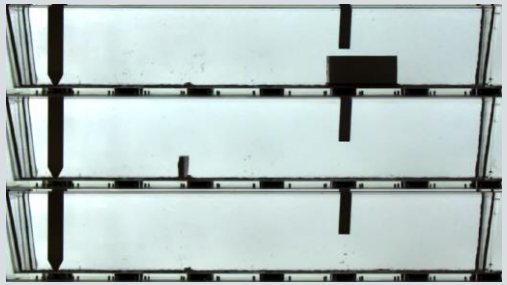




Water modelling

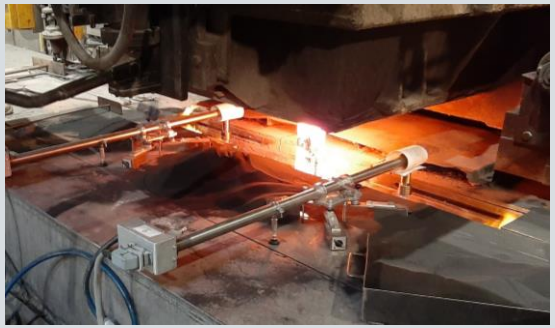
- Fluid Flow analyses in selected metallurgical operation units





Complementary tools

- Mould velocity measurement device
- Application near test rigs for thermo-mechanical testing



Lab set-up

A couple of impressions

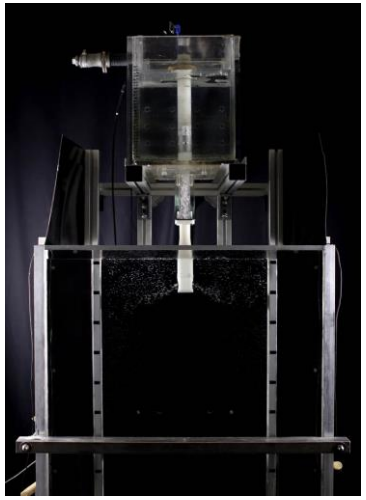
Moulds 1:x
Leoben

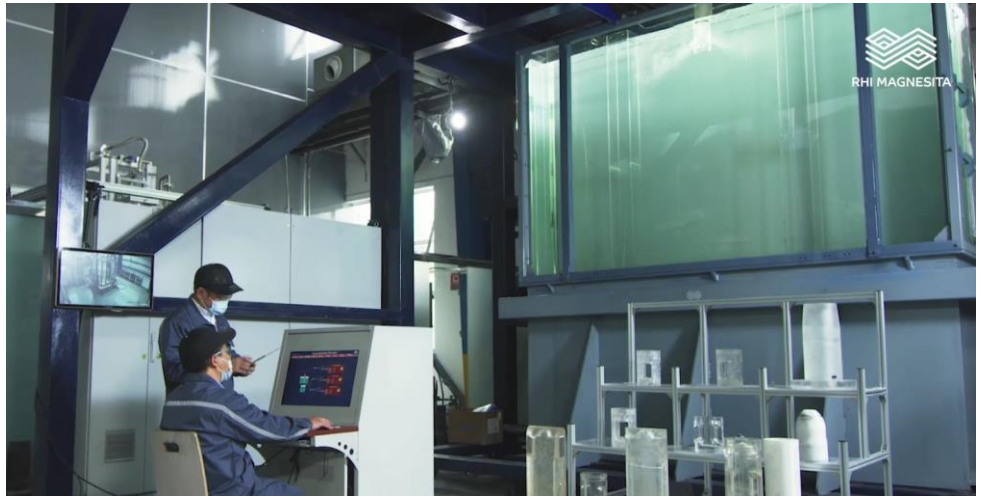
Mould 1:1
Dalian

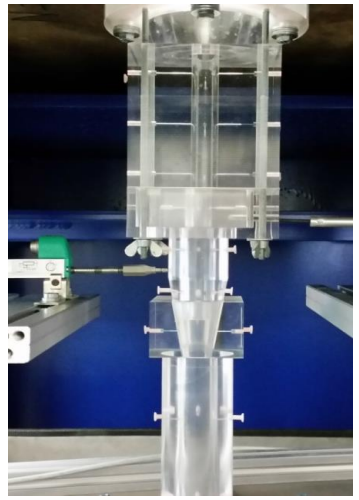
Tundish 1:x
Leoben, Dalian

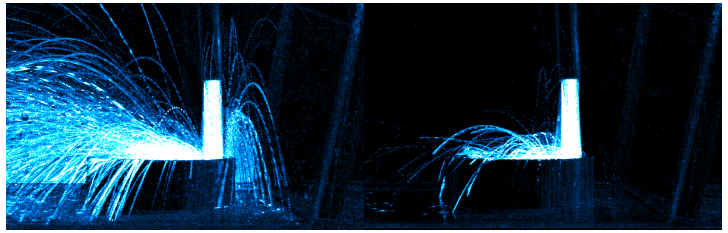
Slide gate
Leoben

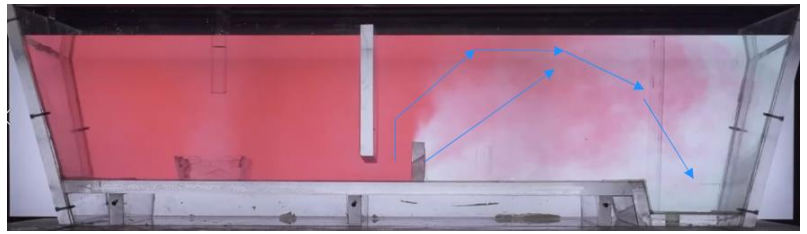
Purging
Leoben, Dalian





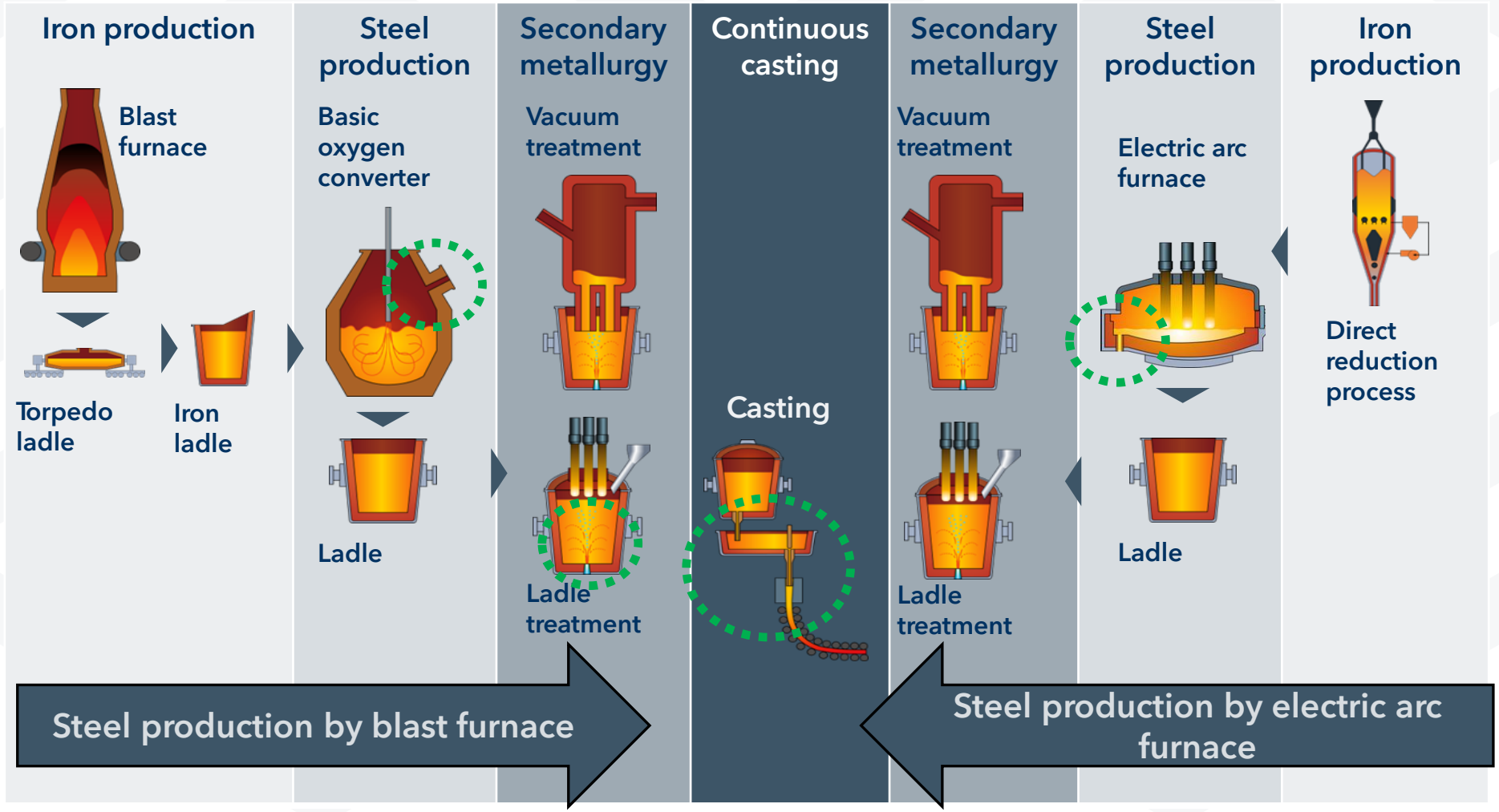






Examples

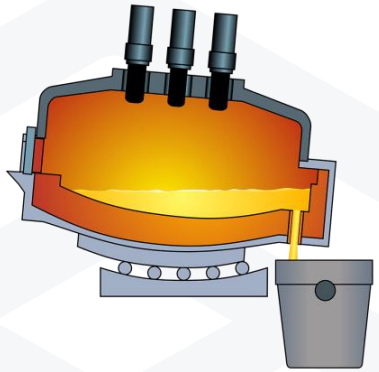
Simulations in the area of steelmaking

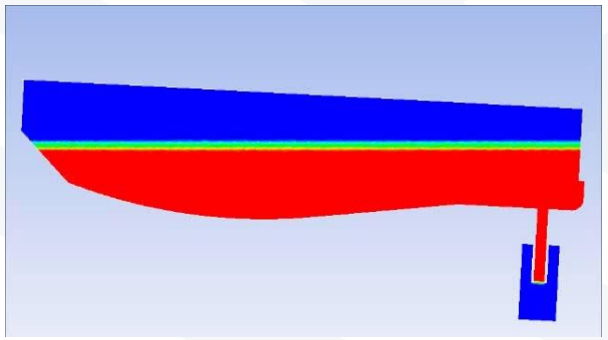


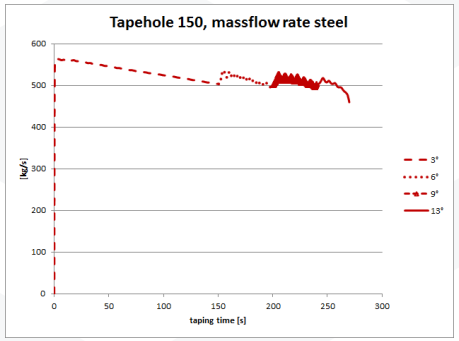
Tapping systems
BOF and EAF

Key refractory element for liquid steel transfer between steelmaking unit and ladle.

- **Tapping time**
- **Slag carry over**
- **Life time**
- **Flow dynamics**
  - Turbulence
  - Velocity
  - Pressure

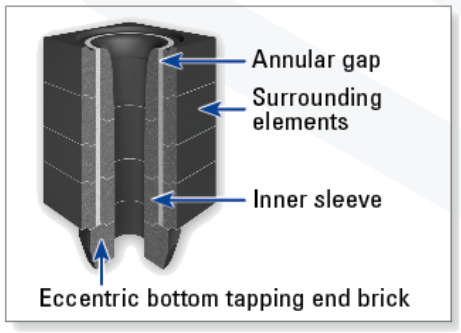


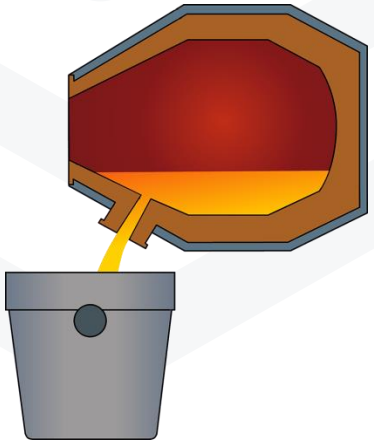


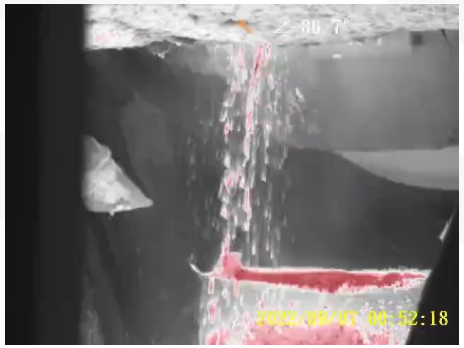


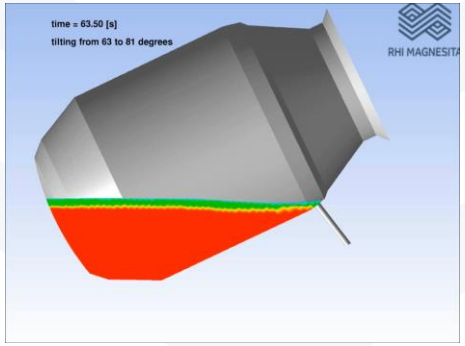
Variant 1, new taphole

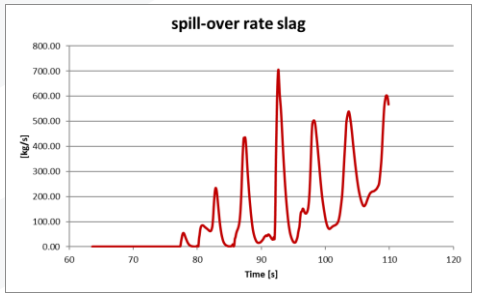
	Tilting angle [°]	Duration [s]	Mass steel in furnace [kg]		Mass flow rate [kg/s]		Steel bath level above taphole [m]	
			start	end	start	end	start	end
Step 1	3	0-150	129000	63070	563	503	0.78	0.43
Step 2	6	150 -200	63070	37332	536	500	0.6	0.43
Step 3	9	200 -240	37332	16874	527	502	0.58	0.39
Step 4 (optional)	13	240 -250	16874	11790	517	508	0.53	0.42







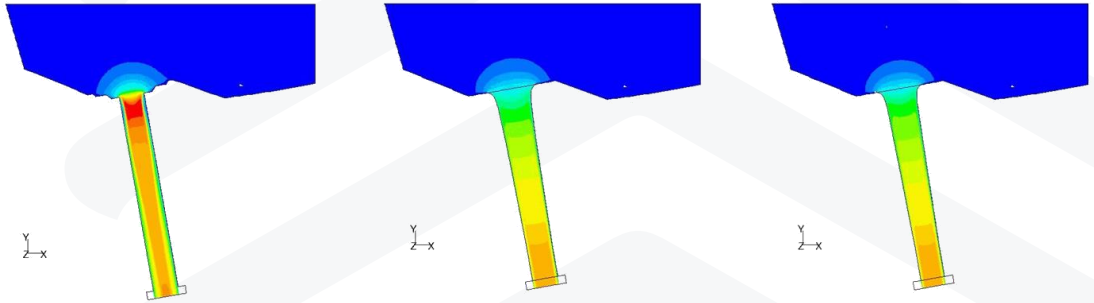


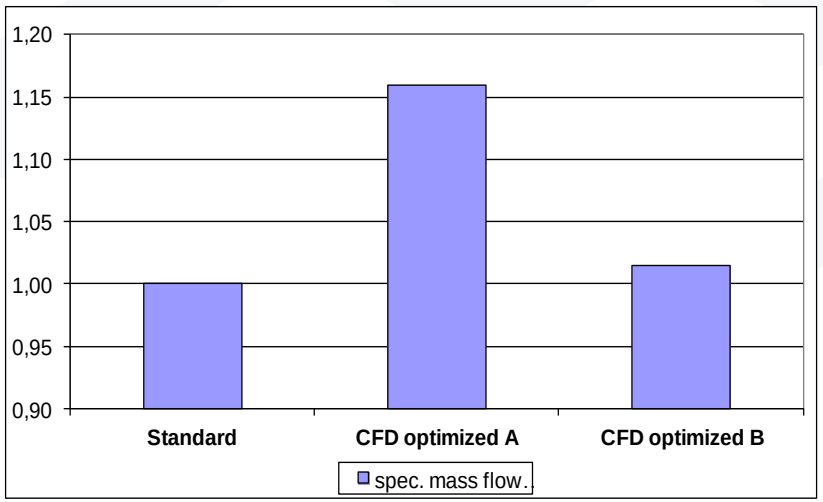


EBT product analysis 1/2

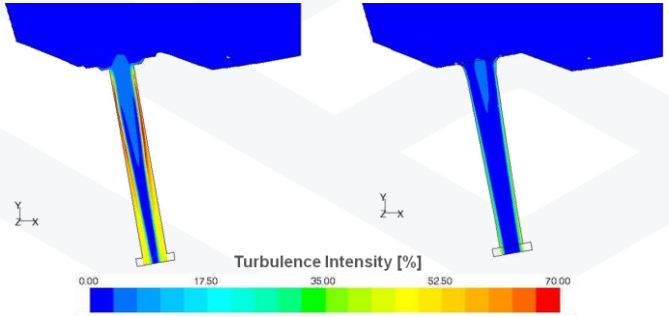
CFD simulations

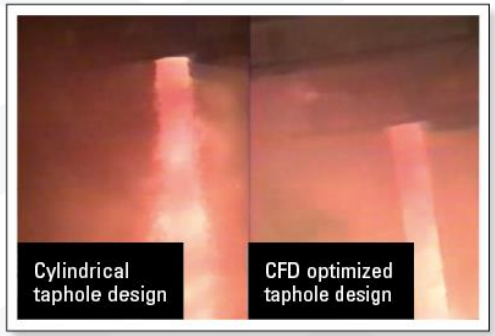
Standard | Optimized A | Optimized B

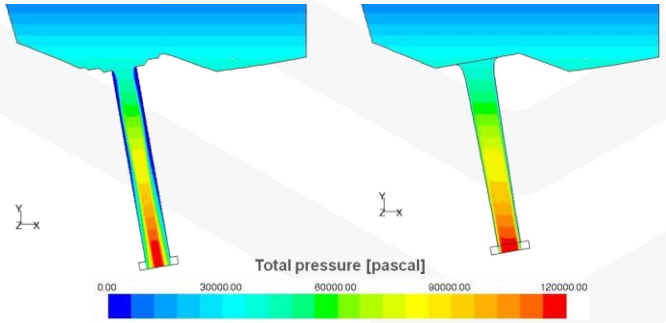


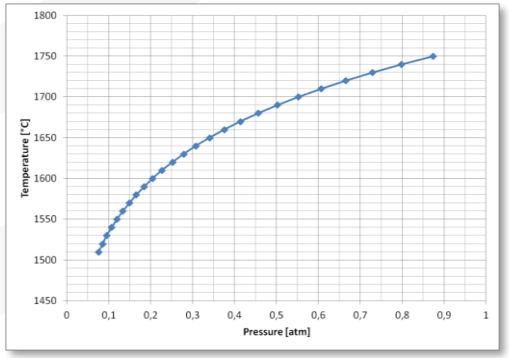


Standard | Optimized







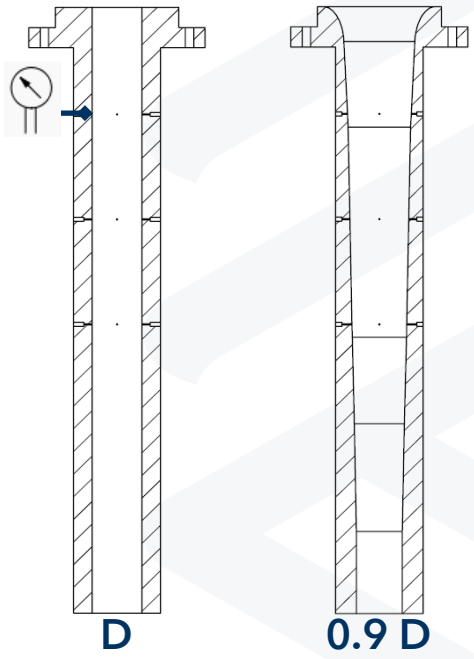


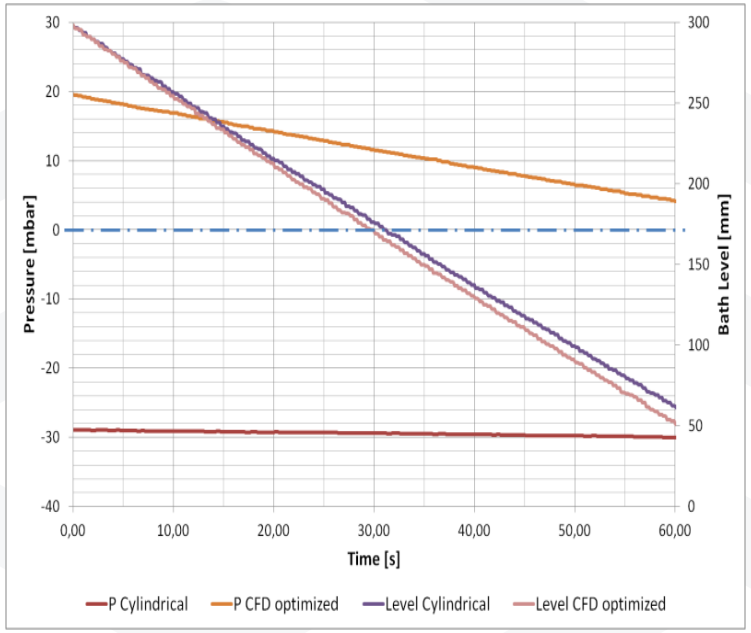
$$MgO\ (s) + C\ (s) \rightarrow Mg\ (g) + CO\ (g)$$

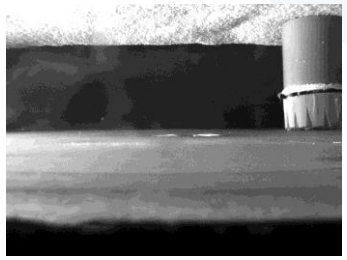
EBT product analysis 2/2

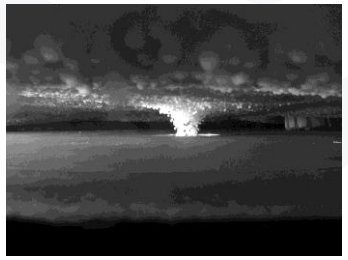
Water modelling and examples from the field

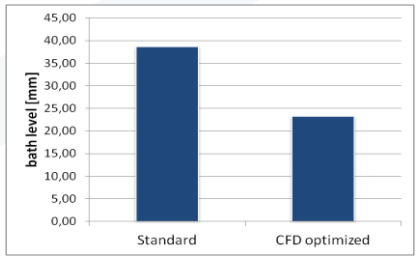
Water modelling results



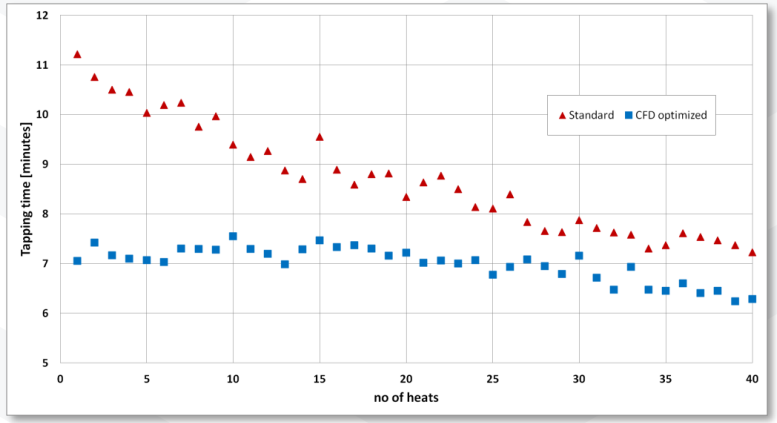


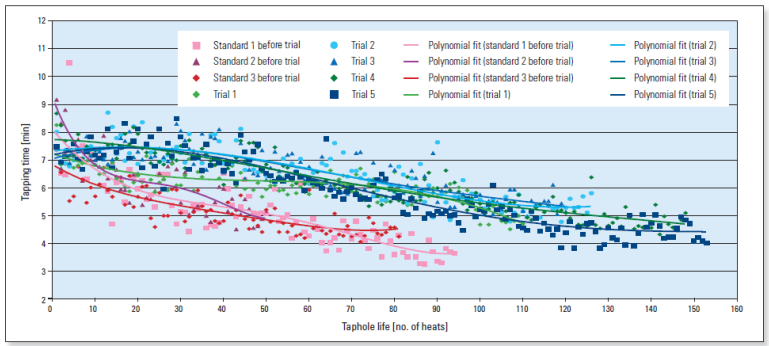






Tap time over lifetime



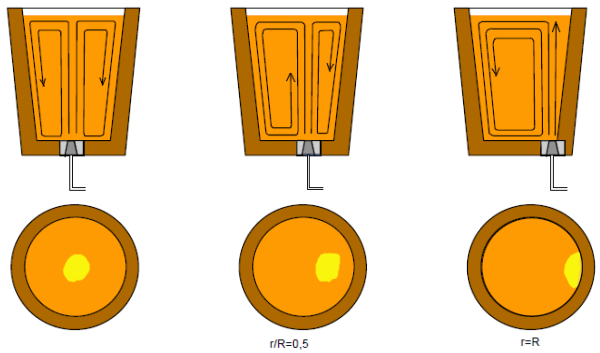


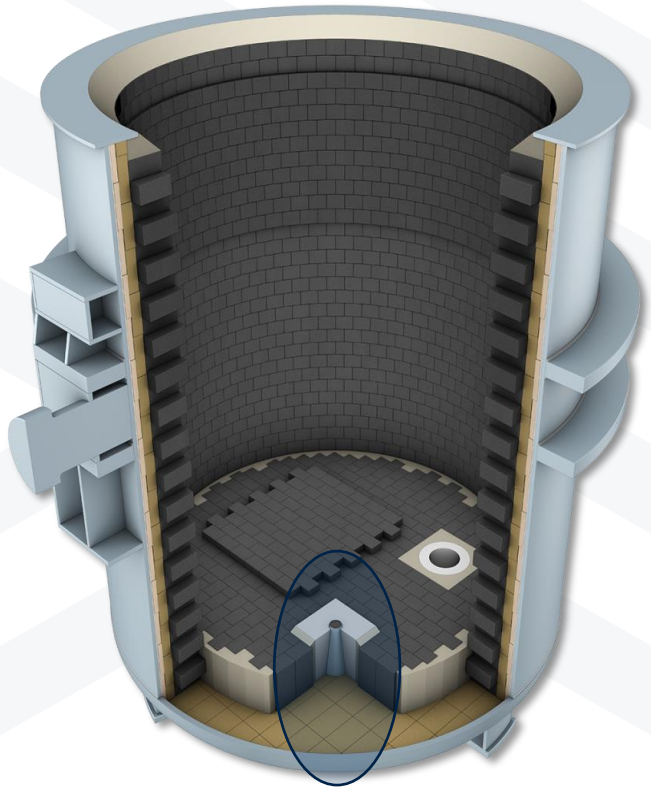
- Reduction of turbulence
- Avoidance of underpressure
- More stable tapping time
- Longer lifetime
- Potentially higher yield

Ladle purging

Used for…

- Chemical homogenization
- Temperature homogenization
- Removal of non metallic particles





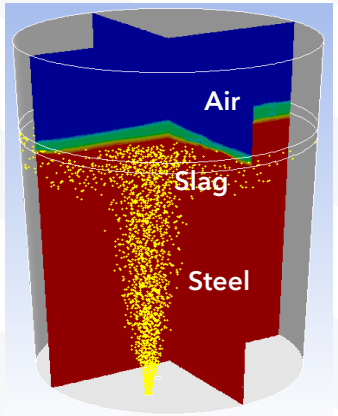
Impact on…

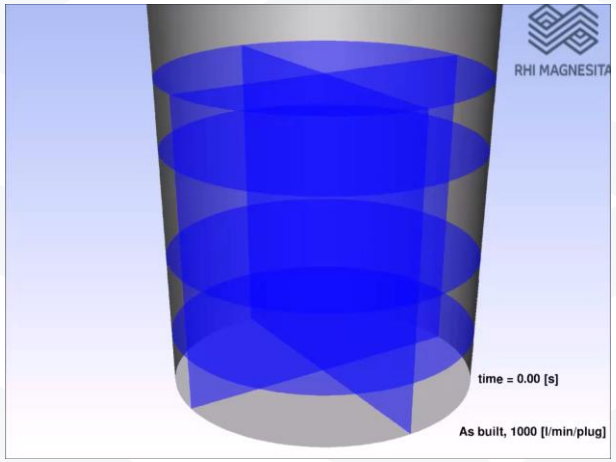
- Wear pattern of refractory lining due to erosive and chemical interaction

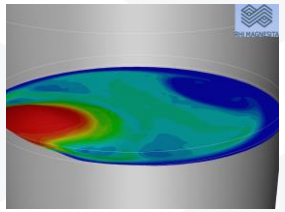
Example

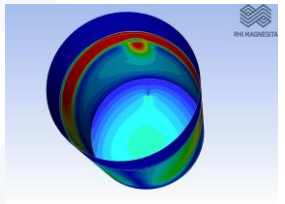
140 to ladle with one purging plug

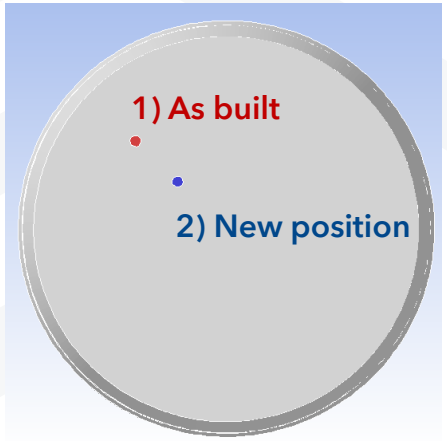
- Unsteady multiphase simulations have been carried out to resolve the fluid dynamics in the metallurgical vessel in a most realistic way.
- Multiphase Volume-of-Fluid (VoF) modelling approach is used considering steel, slag and air as continuous fluid phases with sharp interfaces.
- For modelling of purging gas bubbles, the DPM* (Discrete Particle Model) is applied.
- The flow is considered unsteady and turbulent.

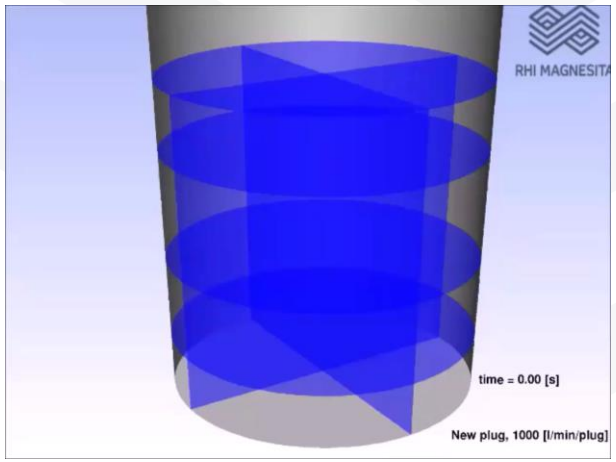


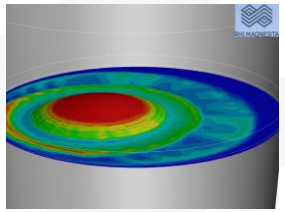


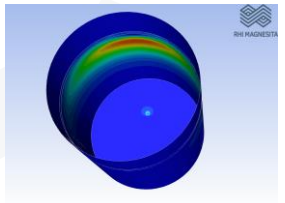








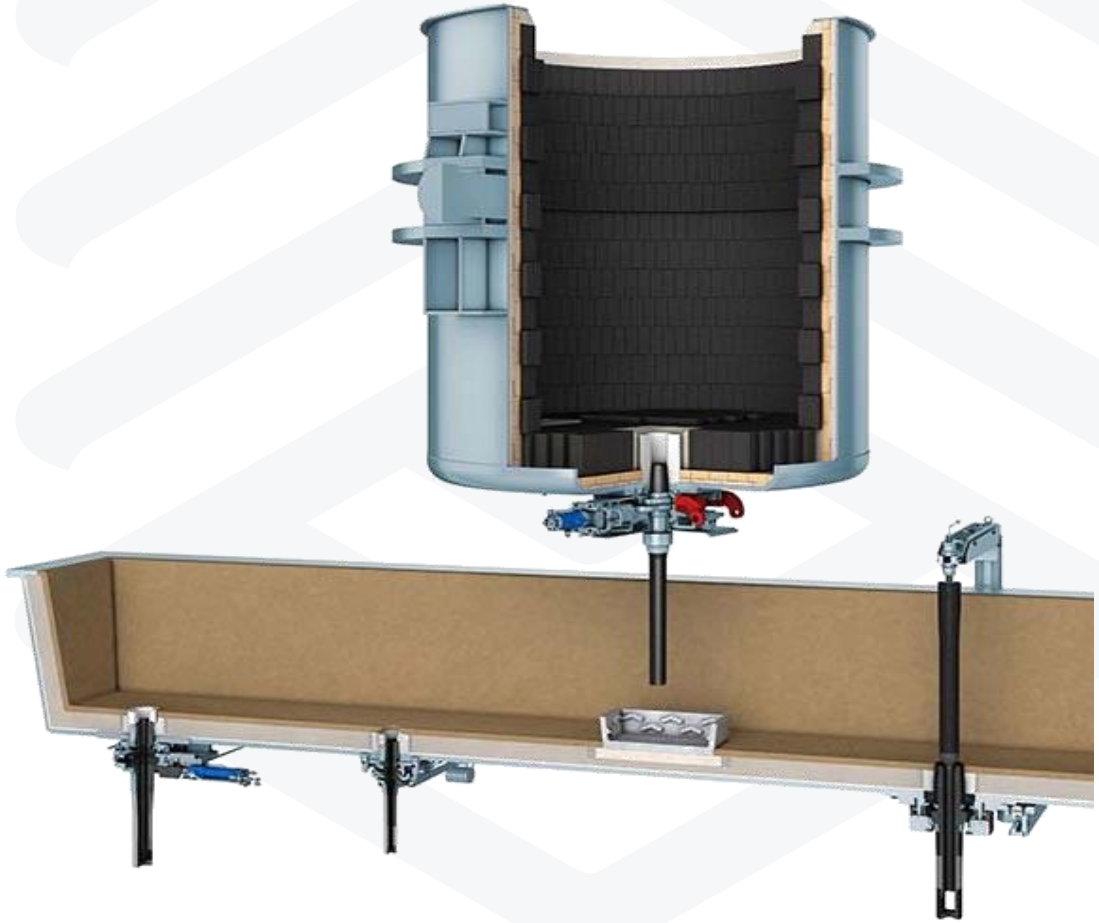




** Modified drag model– former K1 project (S.Pirker)*

Continuous Casting

Ladle2Mold approach



- Slide gate refractories and systems
- Tundish refractories including flow modifyers
- Isostatically pressed products

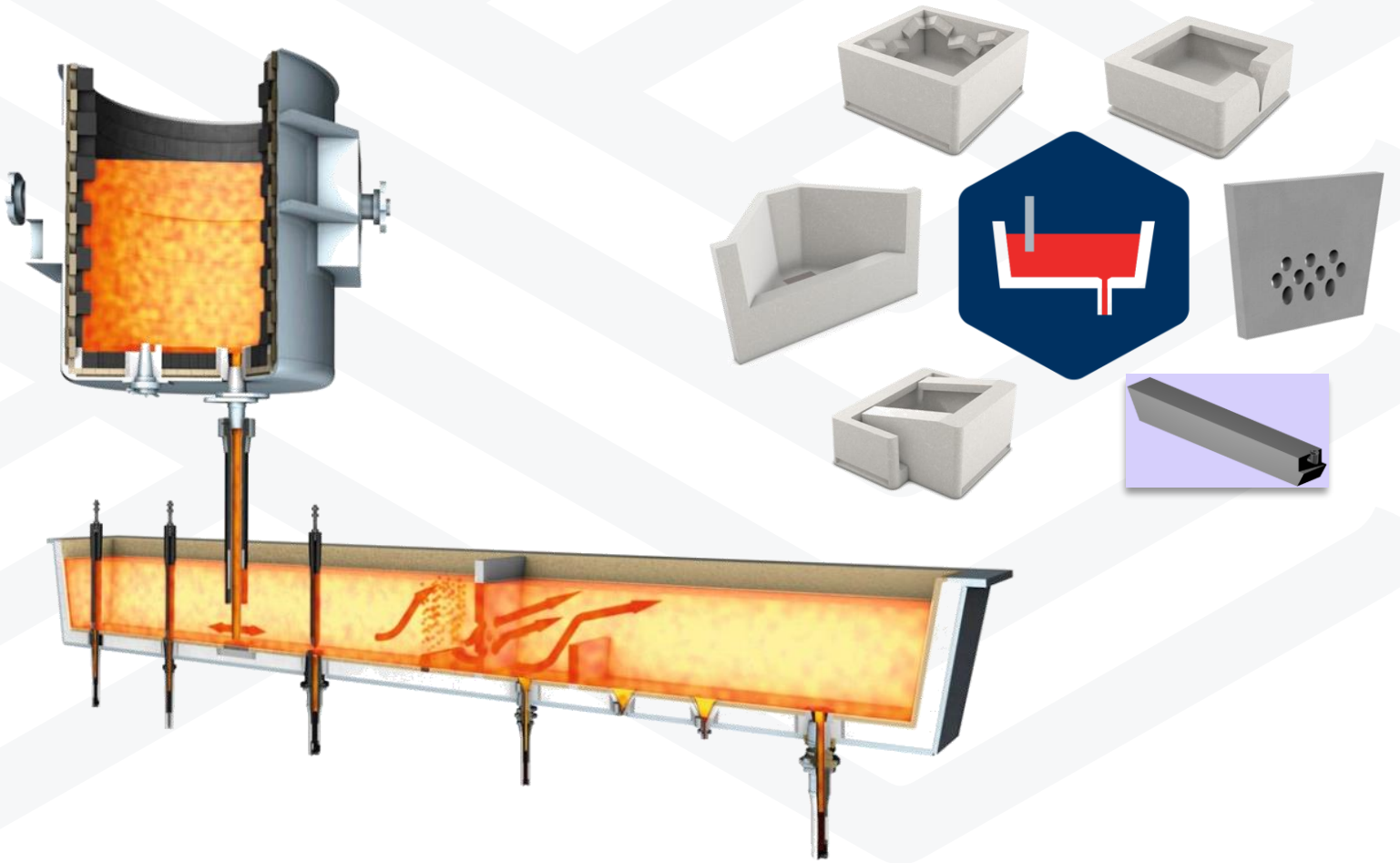
Tundish flow control

Basic function

- Deliver steel to the moulds evenly
- Acting as reservoir and buffer during a ladle exchange

Refining - Tundish metallurgy

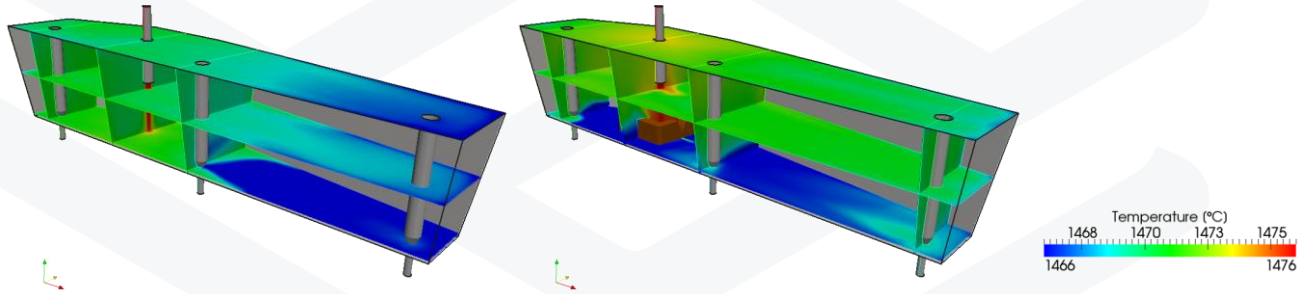
- Efficient separation and removal of non-metallic particles from the melt
- Superheat control
- Thermal and particulate homogenization

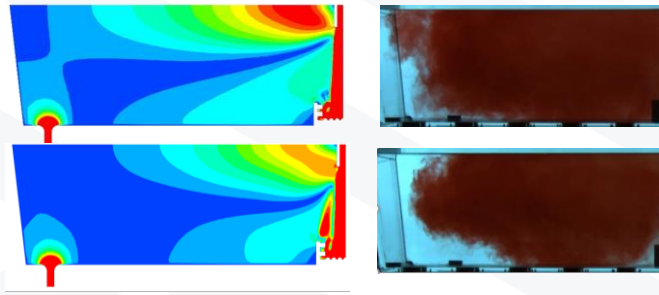


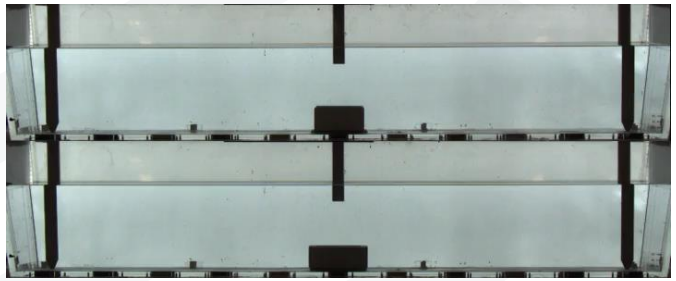
Flow related topics

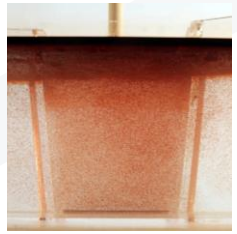
Things we look at

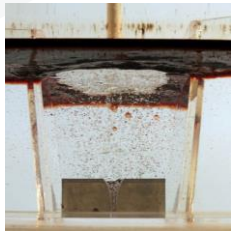
- Optimize RTD parameters
  - Maximize minimum and mean residence time
  - Minimize dead volume fraction
  - Generate a large ratio of plug to dead volume
- Avoid splashing at the start of casting
- Reduce surface turbulence - “Open Eye”
- Limited emulsification of slag during a ladle change
- Avoid vortex formation especially at low levels
- Enhance homogeneous temperature distribution







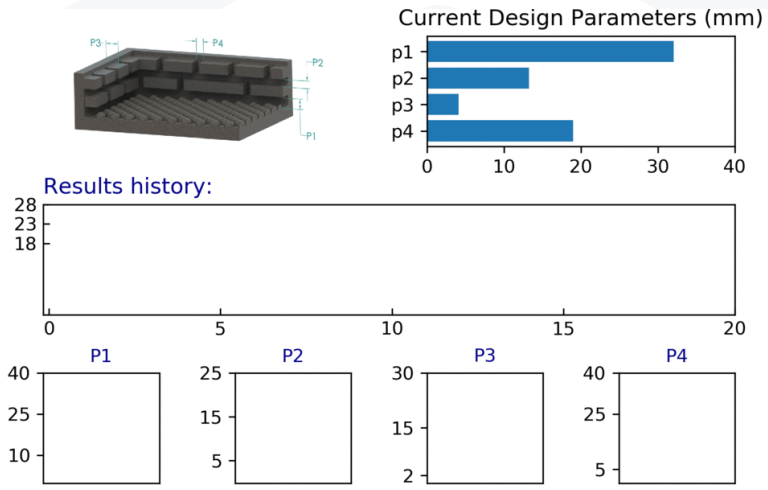


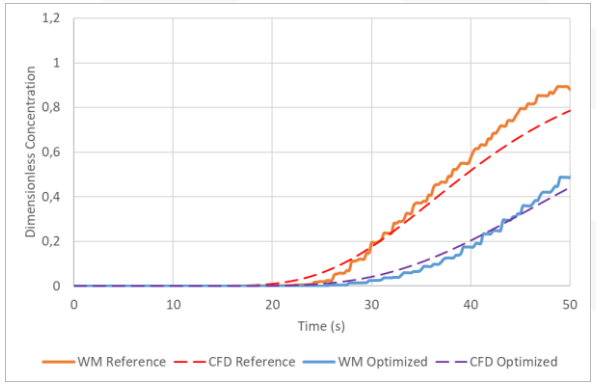


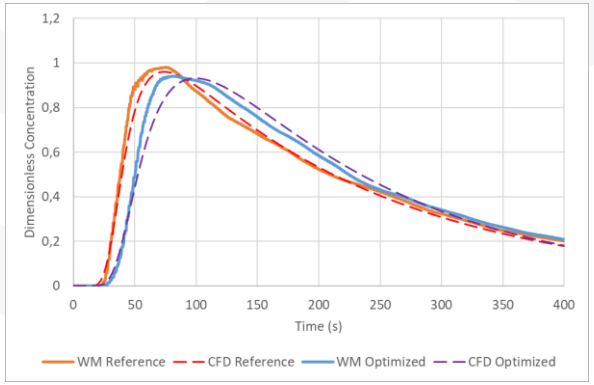
Impact pot /dam weir optimization

Target: min. residence time maximization

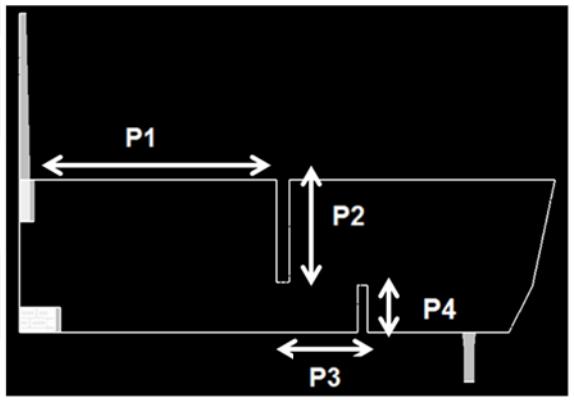
Impact pot

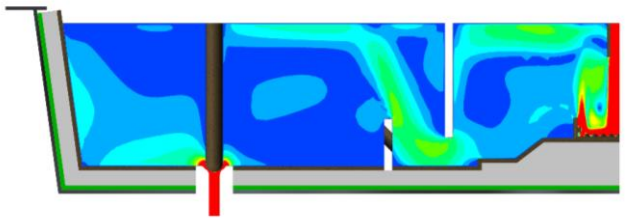


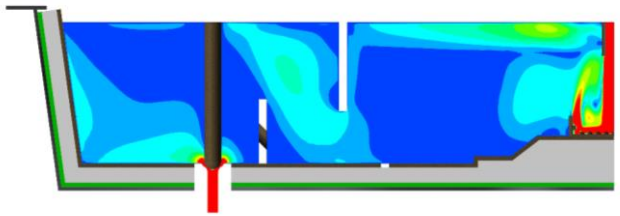


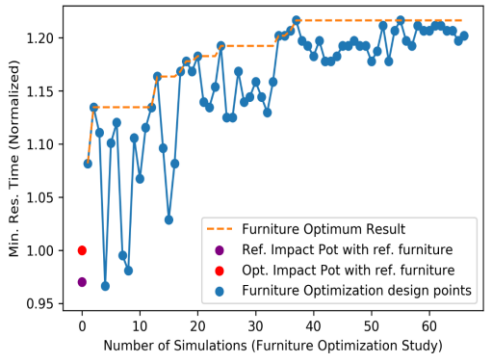


Dam/weir



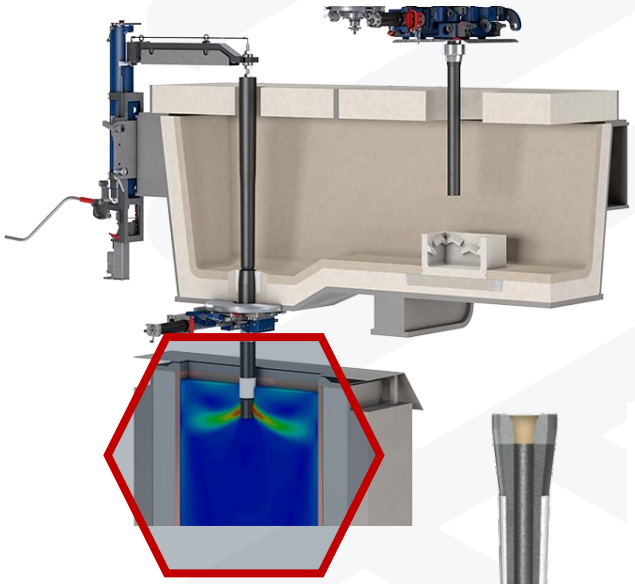






Studying flow in the mould

Why we do it?



Region of interest

Slab | Thin Slab | Billet / Bloom Beam Blank

The flow pattern in the mould is fundamental parameter of the continuous casting process

- Impact on process stability and product quality
- SEN design plays major role

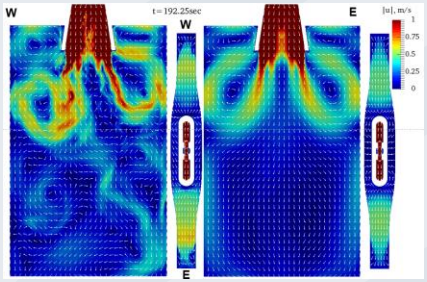
To provide a stable process and minimize product defects, following points (among others) should be fulfilled:

- Smooth surface conditions (uniform surface wave)
- Sufficient upstream flow for mould powder melting
- Avoiding mould powder entrapment
- Maintain stable flow for each casting condition
- Avoiding inclusions and gas bubbles to be entrapped in the solidifying shell
- Propagate gas bubble and inclusion flotation to meniscus

Studying flow in the mould

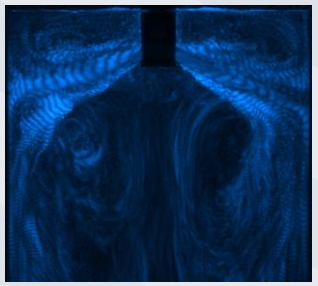
Tools we rely on

Numerical simulation



- Thermal phenomena (solidification) MHD (stirrers and brakes) can be considered
- Turbulence model defines resolution of phenomena – need for validation.
- Multi-phase and highly resolved simulations require high computational costs

Water modelling



- Similar fluidic properties of water and liquid steel (Turbulence, waving)
- Not all similarities can be fulfilled simultaneously
- Thermal phenomena and MHD not considered
- Usually easy to handle (depending on scale and degree of automation)

Liquid metal modelling

CC Simulator SWERIM

- MHD phenomena can be considered
- Density and surface tension closer to the real system
- No visual accessibility
- Alloy is expensive
- More sophisticated measurement technology required

On-site validation

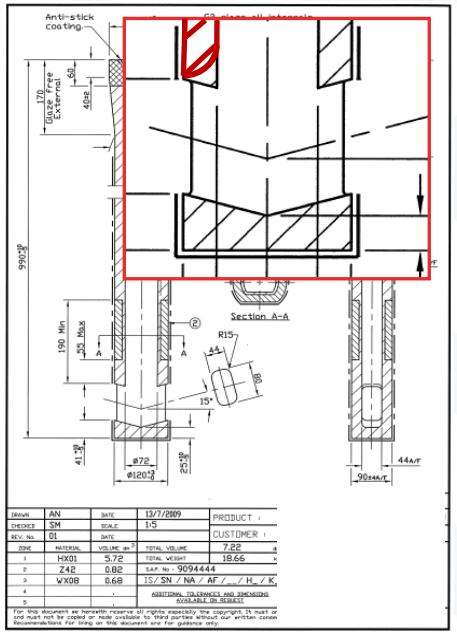
- Provides information about the real process conditions
- Validation of modelling and simulation

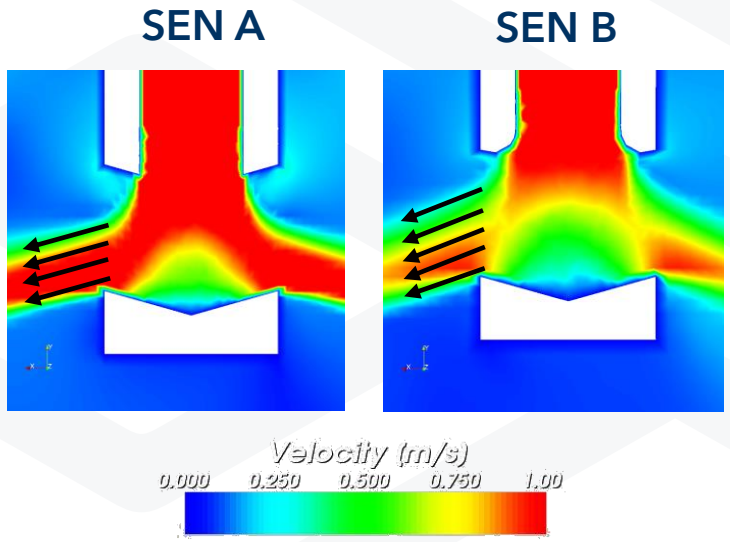
SEN Port modification

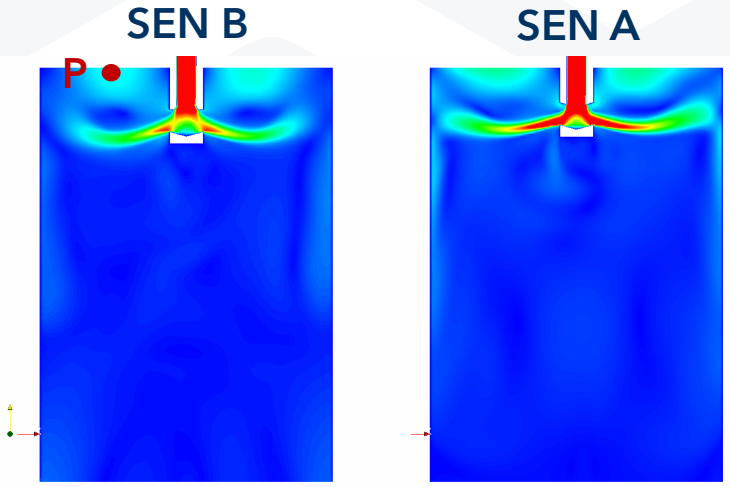
Influence of port Radius

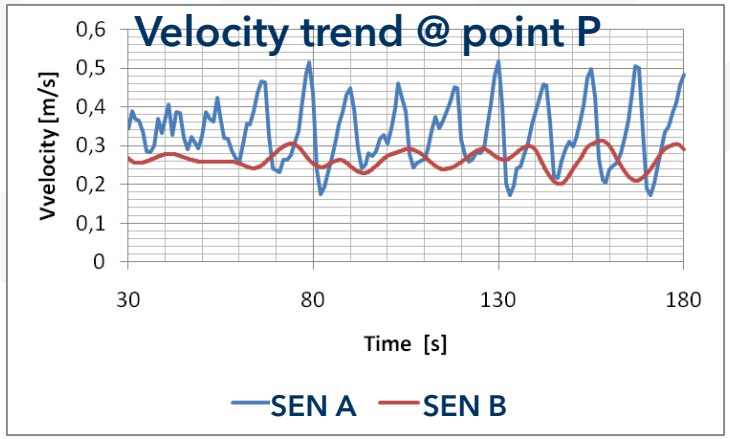
Evaluation of the design feature port radius:

- on the direct flow at the outlet
- on the flow in the mold





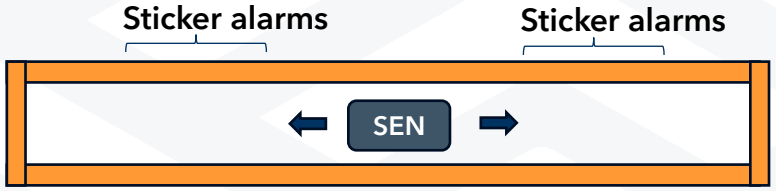


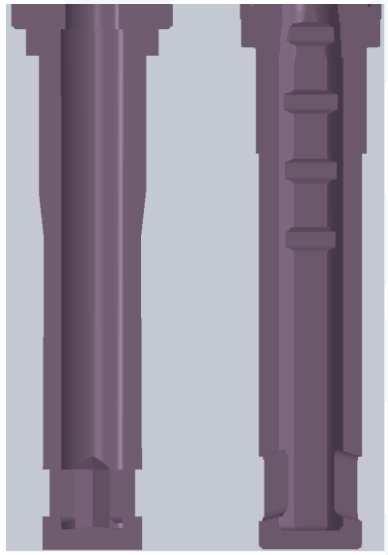


SEN design evaluation related to sticker problems 1/2

Problem statement and project phases

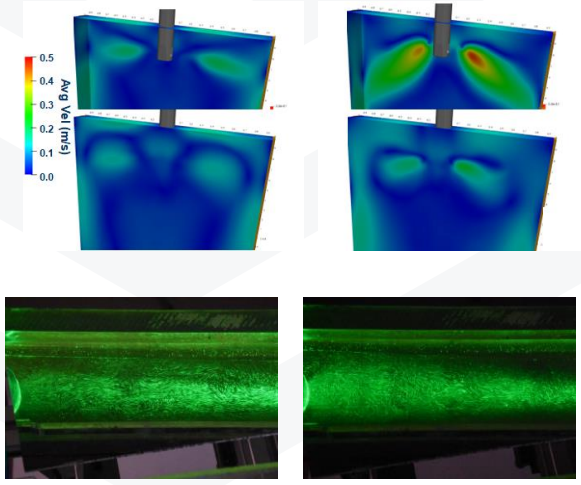
- Sticker alarms with one incumbent design (LB).
- Alarms primarily on one broad face.
- Alarms particularly when running wide and slow.



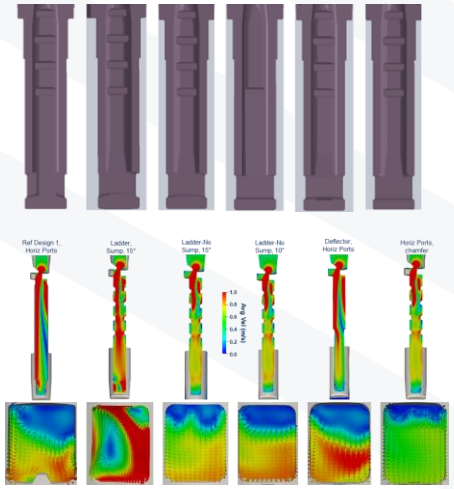


Reference LB

As is situation



Evaluation of alternative designs

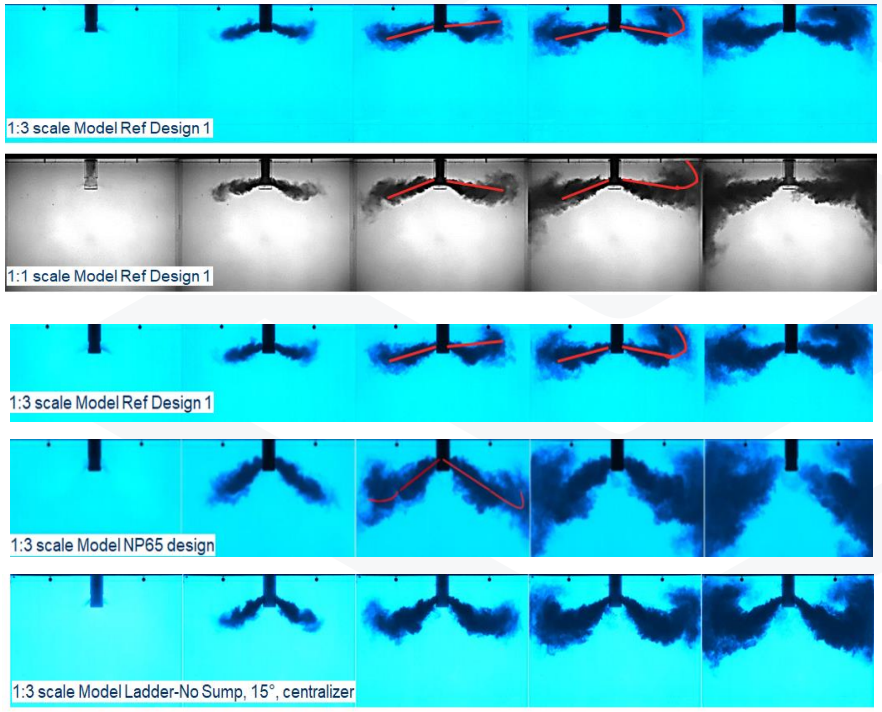


Caster trials

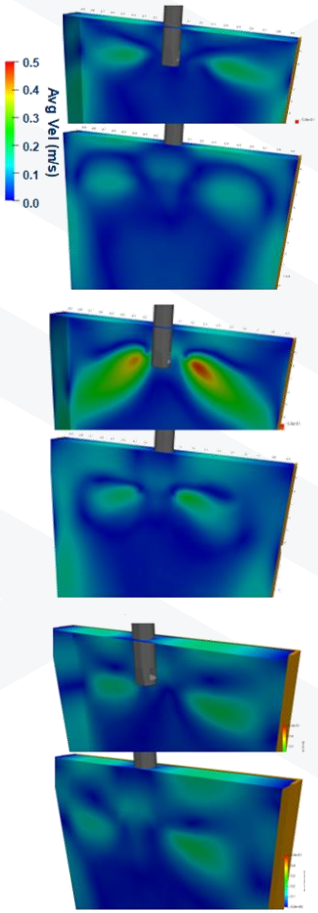
SEN design evaluation related to sticker problems 1/2

Solution and plant results

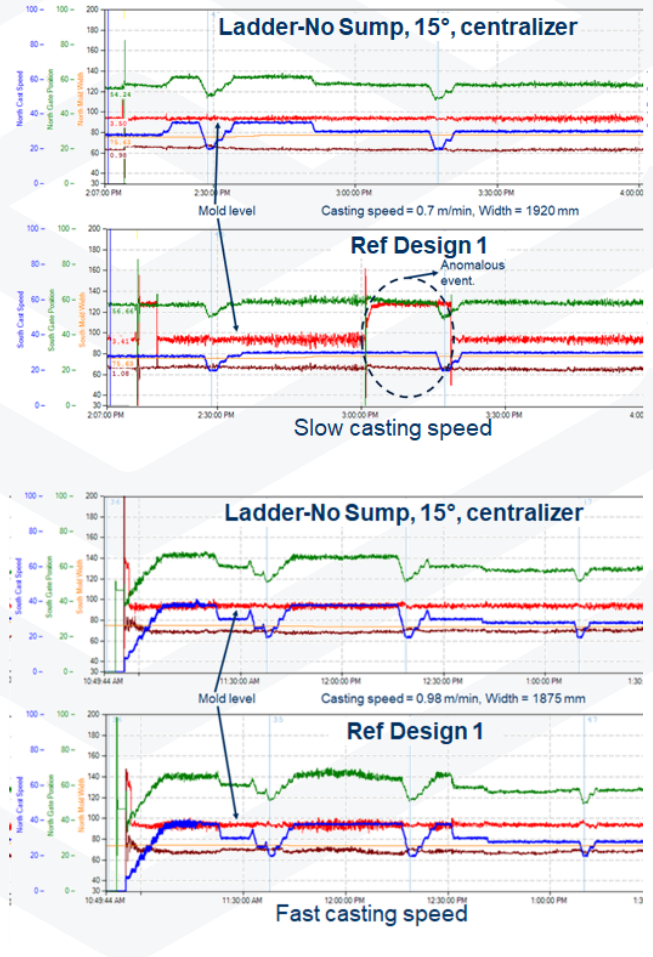
- Centered free jet with low diffusivity
- Sufficient energy transport towards the meniscus
- Low speed fluctuations at meniscus



Dye injection tests 1:1 and 1:3 model



Velocity close to wide sides



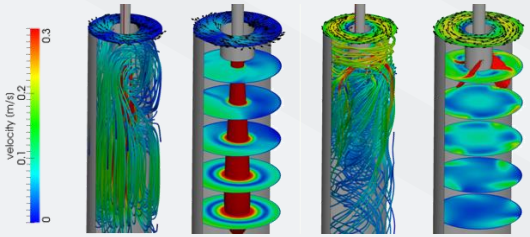
Plant performance

SEN design for bloom/billet casting

GYRO nozzle

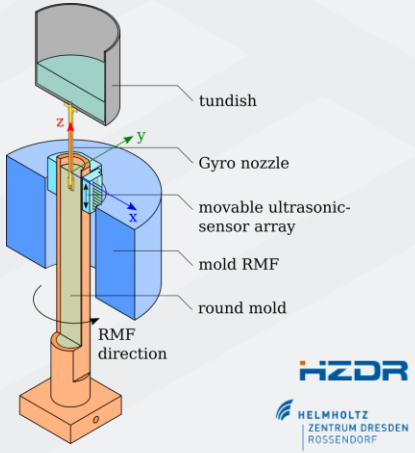
The concept

- Helical port shape
- Avoid deep jet penetration
- Improved energy transport towards meniscus
- Rotational flow without EMS



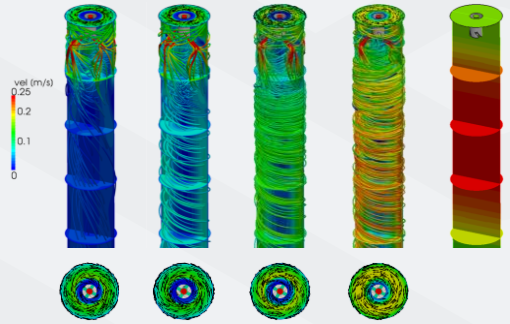
Interaction with EMS - Modelling

- Operated at room temperature with $Ga_{68}In_{20}Sn_{12}$
- 1:3 model of 240 mm dia. round bloom

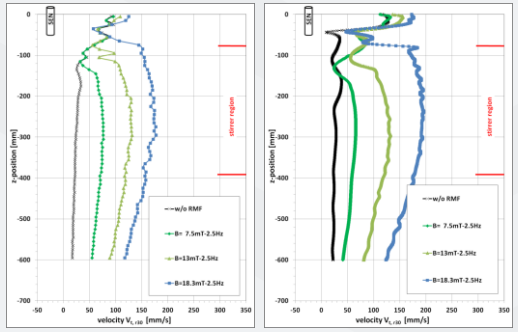


HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Results – CFD* vs. Model



Increasing magnetic field strenght



experiment CFD

Field observations

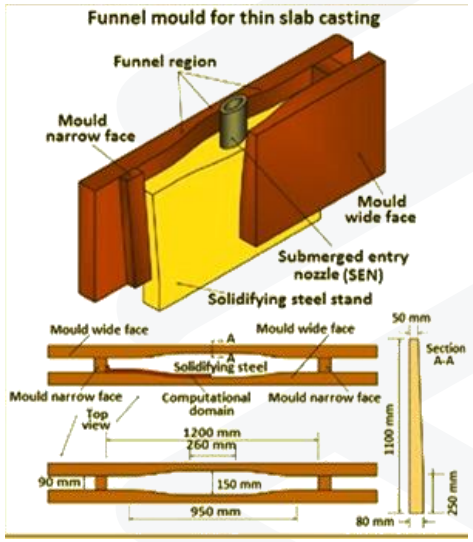
- Improved mould level
- Reduction of grinding losses
- Possible EMS power reduction
- Reduction of oscillation marks
- Higher castings speeds
- Reduction of segregation

** Spitzer model – former K1 project (Javurek/Barna)*

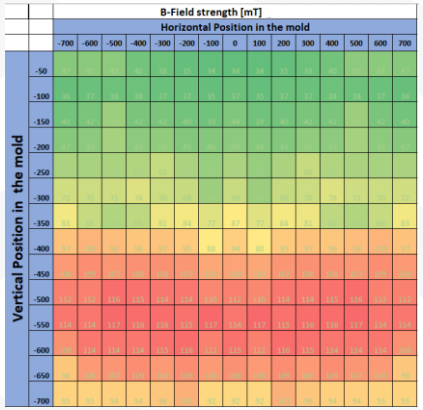
Thin slab casting

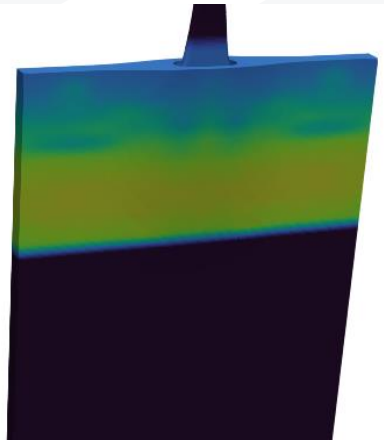
Influence of an EMBr*

Mould



Input

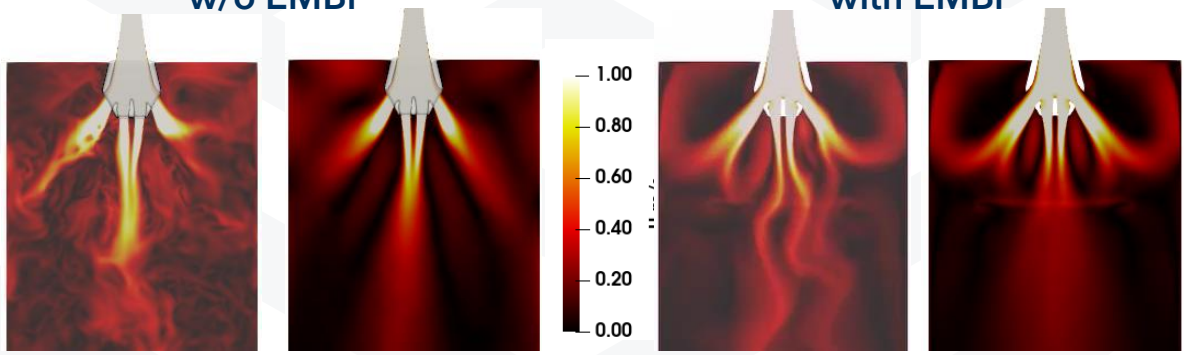




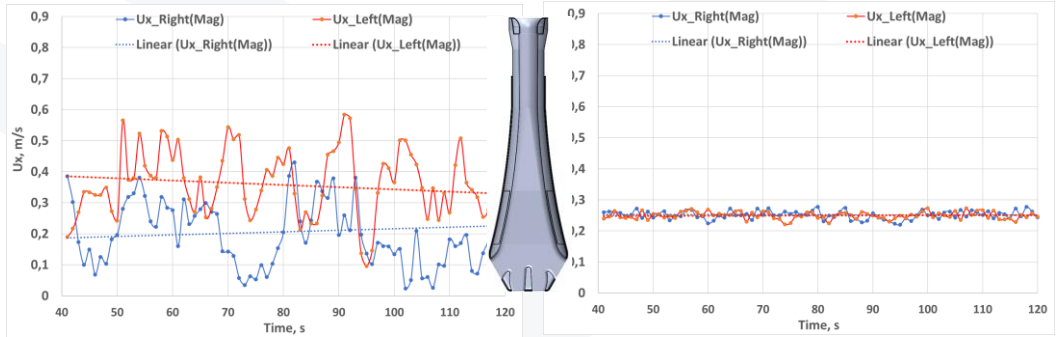
Results

w/o EMBr

with EMBr



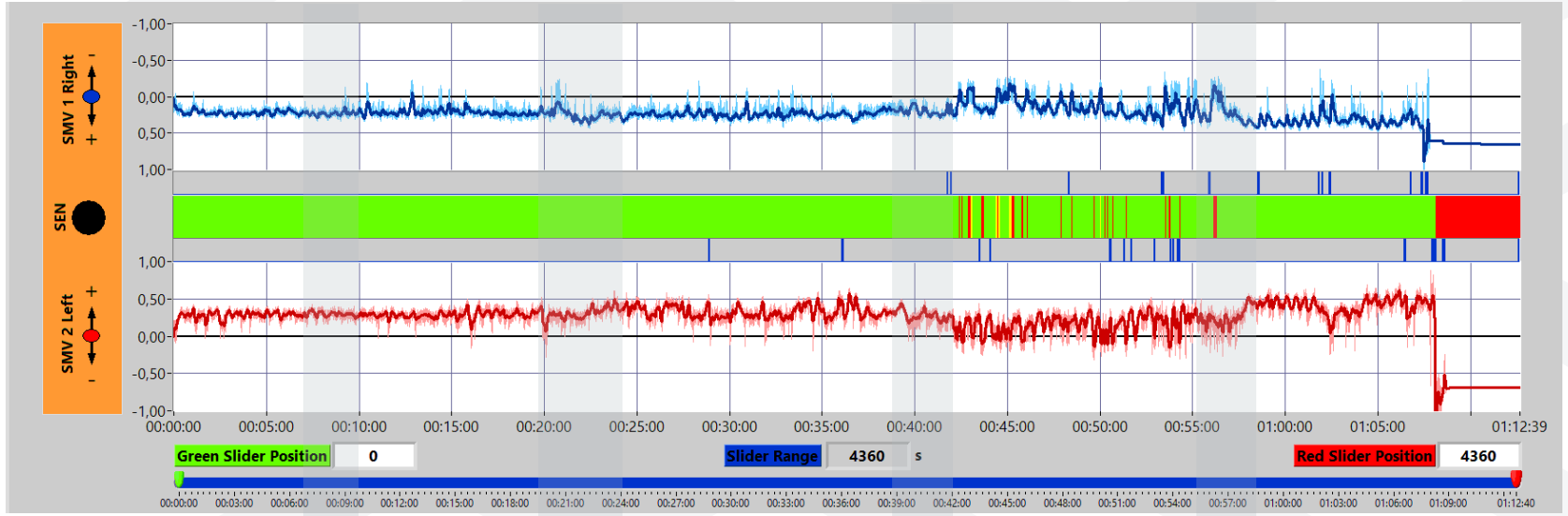
Quarter point velocity trend

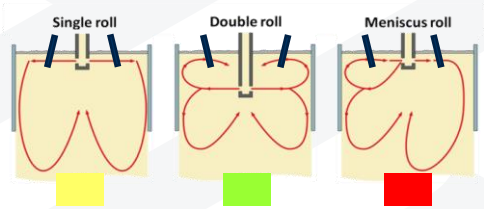


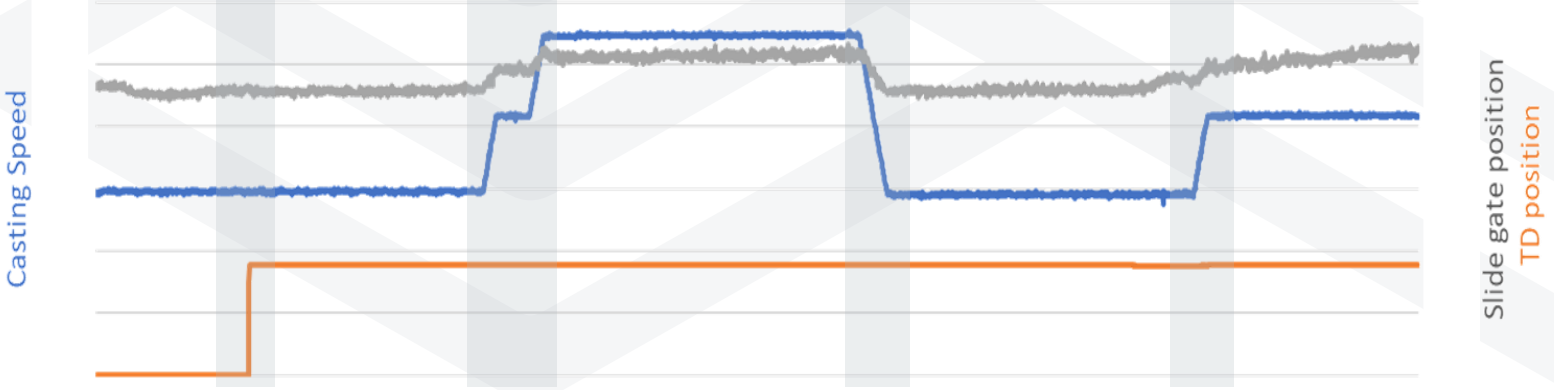
* OpenFOAM MHD solver – current CD Lab (Vakhrushev)

Mould velocity measurement

Influence of operating condition changes







- ~65 min measurement duration
- One tundish position change
- Several casting speed changes during sequence
- Linear slide gate opening increase at latest stage of measurement

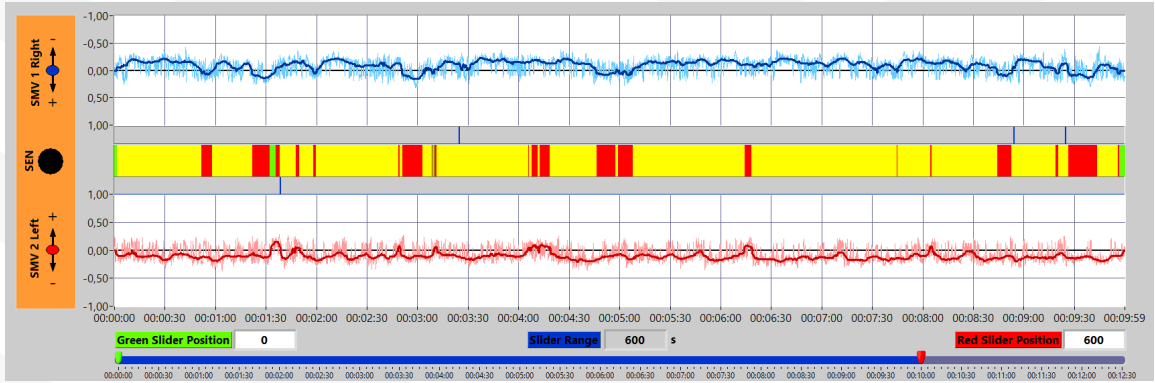
Mould velocity measurement

Same conditions – different pattern?

crack

Air ingress due to underpressure

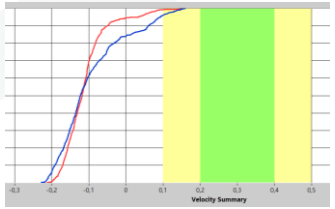
Initial phase, new cast – 10 min



- No changes of operating conditions during measurement
- Same operating conditions as previous case
- Same SEN design

Flow Pattern	min	%
Double Roll	0,1	1,1
Single Roll	7,9	79,3
Meniscus Roll	2	19,5

Velocity Statistics	AVG	STDev
Both:	0,104	0,073
SMV1:	-0,096	0,089
SMV2:	-0,112	0,057



[m/s]

Summary

Over the last years modelling and simulation, both numerical and physical, have become important disciplines at RHI Magnesita in the course of refractory product development and engineering.

It enables more accurate predictions of the material behavior and providing information about any process interactions.

Several examples of applying different methods throughout the steelmaking process were provided to evaluate the impact on performance and efficiency at selected process steps.

AND FINALLY…..

… constant investment in fundamental research is still necessary to help us further improve our understanding of the complexity of the involved interdependencies.